UNIVERSAL LIBRARY
OU_158139
UNIVERSAL LIBRARY

OSMANIA UNIVERSITY LIBRARY

Call No. 542·1/M98L Accession No. 24

Author Murray, D. Stark

Title Laboratory.

This book should be returned on or before the date last marked below.

THE LABORATORY:

its Place in the Modern World

by

D. STARK MURRAY, B.Sc., M.B., Ch.B.
Assistant Pathologist, Archway Group Laboratory, L.C.C.

THE FENLAND PRESS
12 HENRIETTA STREET, W.C.2

First Published 1934

Printed in Great Britain
AT THE PRESS OF BURALL BROTHER
WISBECH, CAMBS.

CONTENTS

		Page
	INTRODUCTION	7

PART I

A Survey

I	THE LABORATORY AND ITS STAFF	9
II	THE RESEARCH TEMPERAMENT	13
III	THE CAREERS OPEN TO LABORATORY WORKERS	19
IV	THE REWARDS OF RESEARCH	36

PART II

The Laboratory in Medicine

V	THE PATHOLOGICAL LABORATORY	41
VI	SOME ROUTINE PROBLEMS	46
VII	THE LABORATORY AND THE PATIENT	53
VIII	RESEARCH IN THE ROUTINE LABORATORY	67
IX	THE RESEARCH INSTITUTE	74

PART III

Research in Other Fields

X	RESEARCH OUTSIDE THE LABORATORY	85
XI	INDUSTRIAL RESEARCH	94
XII	THE FUTURE OF RESEARCH	109

INTRODUCTION

It is my hope that this book will satisfy an existing demand for information on a subject that is attracting an increasing amount of attention and at the same time will stimulate an additional interest in the relation of scientific research to industry and to the whole life of the nation. It cannot do more than touch upon the chief types of laboratory and methods of research and is only intended to give a general outline to those who have no means of collecting the information for themselves. Nevertheless, it may make those who have a closer connection with scientific methods take an even greater interest in the possibilities of research.

In preparing the book I have visited many laboratories and have to thank a very large number of scientific workers for the time and trouble they have taken in showing me their laboratories and telling me of their problems. In true scientific fashion they endeavoured to assist me with my task, that of collecting information of interest to the general reader, and I have tried in what follows to repay that assistance by giving an accurate account of what is going on in laboratories all over the country.

CHAPTER I

The Laboratory and its Staff

Romance and the laboratory are almost invariably associated in the public mind. The name brings to most people a vision of white-coated scientists bending over tubes, bottles and weird apparatus, making wonderful discoveries. The discovery may be on the one hand a new death-dealing poison or, on the other hand, a new drug that will cure man's worst disease. Fiction is full of stories of laboratories but these are hardly as romantic as some of the real discoveries that have been made.

Laboratories, as we shall see, serve many purposes and the equipment and general plan of each depends on the exact problems with which they are intended to deal. Some, while still retaining the same and certain characteristics are so highly specialised that a brief description cannot cover them. But, in general, laboratories closely resemble each other in appearance. Well-lighted benches across or under large windows; benches equipped with sinks of various sizes, abundant gas jets and electric light plugs

form the basic furniture. Cupboards of various kinds and various tables for special apparatus take up the remainder of the space. The biologist is distinguished by his microscope, the chemist by his tripod and boiling flask, but otherwise they work in very similar rooms and atmosphere.

The workers vary at least as much as the problems they tackle but here also there is a common basis, a foundation of training in methods of observation, calculation and deduction. Except in a few very specialised laboratories workers who have had a general training usually possess sufficient knowledge of the technique of a variety of subjects to be able to apply to a problem a variety of methods borrowed from other branches of science. We shall have occasion to mention this repeatedly, for modern industry and modern science are always ready to take from any science methods and ideas of value to themselves.

The workers in any laboratory are usually sharply divided into two classes. There are those who have studied and are qualified to give an opinion on the whole subject dealt with by that laboratory, and those who have a knowledge only of the routine methods used. The former are the skilled and usually academically qualified experts in the subject; the latter constitute that very important profession, laboratory assistants or technicians.

It must be understood that much of the work

of a modern laboratory consists of carrying out standardised tests which can be done with great accuracy by people who have no understanding of the fundamentals of the subject. In large laboratories there are often processes which can be divided among a number of workers and one sometimes finds a technician carrying out certain measurements with meticulous accuracy without any very clear conception of the process as a whole, much as in a modern factory workers may be busy doing one operation which at first sight bears no relation to the finished product. However, the really good and efficient technician knows most of what there is to know about his subject and especially its methods.

There is no organisation representing all laboratory workers so that one cannot give any figure as to the number in this country. The number has increased very rapidly and is still increasing. Research was formerly a mysterious process carried out by a few scientists in small laboratories. To-day it has assumed relatively enormous proportions and has spread into fields that formerly were considered outside the range of its activities. So long as research concerned itself only with the search for knowledge it stood outside the commercial world; once it was shown that research could effect economies in time or cost, that it could initiate new manufacturing processes and improve others, research became a

necessity for most industries. To-day the position is that many industries, rayon production, drug and dye manufacturing, the compounding of new metal alloys and so on, have arisen from and are actually built on a foundation of laboratory work. Such industries not only require laboratory work to keep their processes going but must continue research to further improve their products and methods of production.

All this has meant a call for more and more workers in the laboratory field and questions of how they are to be recruited and how paid have not been worked out on any recognised basis, although to-day there is a fairly uniform system in regard to such matters. In this respect the popular conception of the laboratory breaks down, for it cannot be considered a place where only romance exists. The laboratory worker regards his work as a career from which he hopes to gain certain material rewards; but there is still one thing the laboratory worker does crave and that is freedom to tackle his problems in his own way and without interference from those who do not understand either the problems or the methods that may be employed. In this way he does have a chance to make that romantic type of discovery which is still possible and distinguishes the career in scientific work from other methods of gaining a livelihood.

CHAPTER II

The Research Temperament

Traditionally the chief characteristic of the research worker is a marked degree of absent-mindedness and an indifference to the ordinary things of life; but, as is the case with many traditional pictures, most laboratory workers are no nearer to this type of person than are the rest of humanity. It is true, however, that the man who is to make a success of research must be capable to a very large extent of confining his attention entirely to the problem he is investigating. This does not mean that he should be blind to other problems and other branches of the subject, but that he must refuse to be drawn aside by chance observations. Chance observations, it is true, have been of immense importance, but they must be examined in their proper place in relation to the work being done on the problem as a whole.

In most cases laboratory workers are prevented from becoming too narrow in their outlook because they usually have a certain amount of routine work to do. As we shall see, there are

institutes where only pure research is done, but in the great majority of places the research is being done alongside the routine work. By organising the work in various ways the research worker may be relieved of much of the routine, but the fact that it is going on around him still keeps him, to some extent, tied to it.

Research may, of course, arise from the routine work, in contrast to research of an absolute nature in which the connection with everyday problems seems exceedingly remote. By absolute research one means inquiry into the fundamental nature of materials and phenomena. Such research is carried out with no practical object in view, but it may come to have the very closest bearing on practical problems. Some of the greatest of all scientific discoveries have emerged in this way. Indeed it is probable that much of man's knowledge has come not from his need to solve practical problems, but from his curiosity as to the structure and mechanism of things around him. Leeuwenhoek, the Dutch microscopist of the seventeenth century, made the first discovery of bacteria without any intention of discovering the cause of disease and with no idea that the things he saw in his primitive microscopes would later be proven to be of such importance to man.

Routine work in most laboratories consists in the carrying out of tests of recognised value and

by a standardised technique. They may, however, form the basis of research, not into the basic facts, but by correlation and comparison, into certain aspects of the subject. Where conclusions are to be drawn on a statistical basis very large numbers of strictly comparable tests must be done. When it is desired to establish a figure that can be regarded as "normal" it is necessary to make a sufficient number of tests to cover all possible variations.

A further form of research which often arises in connection with routine work concerns the adaptation of methods. Although a method of doing a certain test may have been generally accepted as accurate and simple, it may be susceptible to further simplification. When large numbers of any test have to be made, and especially when they have to be made by different people, laboratory workers are constantly trying to simplify the methods so that errors due to different observers will be eliminated.

The man who is actually utilising the method is the one who usually thinks out these modifications and it follows that he may be either of the technical or scientific staff. Such modifications may arise from inspiration but more often they are shown to be valid only by long and careful experimentation. In fiction, research is always depicted as a matter of brilliant inspiration. It is true that discoveries have been made by experi-

ments suddenly conceived, but the greatest number of discoveries are the result of hard work and concentration. Very often the hard work is not all done by the man who claims the final victory. Few new facts are discovered without much reference to work that has gone before, and research workers are usually careful to give a list of all the previous scientists to whom they owe many of the steps to the final result. Inspiration is of the greatest value in summing up, as it were, the work of others. Certain problems are so complicated that even when almost every fact has been collected the final solution may still be elusive, until inspiration shows how the last discovery needed to link up all previous work can be made. Thus, for example, it was for many years thought that the pancreas gland was in some way connected with diabetes and almost innumerable experiments had been carried out to show this connection. But it remained for Banting and Best to see how all these experiments and observations required one final proof: an experiment which led to the discovery of insulin. Sometimes the inspiration merely indicates the essential problem but does not provide the method of attack. Thus, it is related that a manager of a cotton-weaving firm had the sudden idea of giving cotton the characteristics of wool so that it would be uncrushable. The chemists who were asked to solve the problem found it needed more

than inspiration, but they succeeded after fourteen years and in the process carried out an enormous amount of research.

There is the case of Ehrlich, the German scientist who got the idea that somewhere in the chemical world there should be a drug lethal to each type of germ that infects man, yet harmless to the tissues of the human body. Keeping this constantly in view he began his great research on arsenic and its compounds. As everyone knows he reached compound No. 606 before he found the first substance that combined the properties of being poisonous to a particular germ and relatively harmless to man. This arsenical compound at once changed all ideas of how syphilis should be treated, but Ehrlich continued his work and when he reached compound No. 914 was able to give medical science an even more potent weapon against that dreadful disease.

Nowhere, perhaps, are the qualities of hard work and persistence better seen than in laboratories where physical science is applied to industry. Years have been spent, for example,—and much incidental knowledge has been gained in the process—in the production of a filament for electric lamps. We now have filaments that give constant illumination and possess great strength and durability, but to achieve this has meant an endless process of experimentation. The method of drawing a tungsten filament, as

now carried out, appears so complicated that, to anyone not accustomed to the painstaking processes of science, its conception would appear outside human ingenuity.

In all these problems, no matter how they arise and no matter whether they mean a few hours or many years of work, the research worker requires one chief characteristic: He must have keen powers of observation and patience in face of difficulties, but above all he must be able and anxious to obtain from every experiment the maximum amount of information. From every experiment and test he must extract all the information that has any bearing on the main problem before him.

CHAPTER III

Careers open to Laboratory Workers

We have already suggested that there is probably no field of human endeavour, since the century began, that has shown such an advancement as laboratory research. It is not only that the technique of research has advanced but that the whole field of knowledge that can be investigated by laboratory methods is constantly widening. A generation ago one could have said that the greatest volume of work was being done, and the greatest number of workers were employed by academic laboratories. To such an extent have industrial and special laboratories of various types increased that this is probably no longer true. Nevertheless, the universities remain the centre of the research world, and to the academic laboratory the other laboratories not only look for results but for inspiration.

In the academic world there are a large number of laboratories all tackling different subjects. The workers in them are, of course, rarely engaged entirely on research, for their duties almost invariably include the teaching

of students. The time spent on this duty varies in different subjects and many research workers find that it is an unfortunate encroachment on their time: but there are subjects—and medicine is one of them—where the teaching of students is markedly beneficial to the teacher. The man or woman who has to face the questions and criticisms of a body of students must know his subject thoroughly and must be constantly trying new methods and studying the results of others.

There are advantages in working inside a university, for not only is there always a very complete library, which makes reference easy, but there are, also, other scientists around one who can quickly be consulted, should information be desired on a subject other than one's own. The chemist, to take an example, formerly concerned with methods of isolation, purification and identification of natural subjects has to-day to take into consideration so much of physics that the two branches of knowledge largely overlap.

The chemist is still, from the lay point of view, the typical laboratory worker, seeking to show the fundamental nature of the substances he handles. To-day, however, it is not enough for the chemist to isolate an element, and to identify its atoms by their various chemical affinities. Modern research has revealed that there are

more fundamental discoveries to make and the chemist, aided by the electrician and the physicist, is now engaged in splitting the atom. Recent work has shown that not only can the atom, once the conception of the indivisible, be broken up, but that in what was once thought to be a pure substance there may exist two different types of atoms. Water, used in many sciences as a standard for certain units of measurement, has now been found to consist of two different atoms with divergent characters.

There are at universities, laboratories where the work appears more static than in chemistry, such as the Botanical and Zoological laboratories. It is true that the identification of plants and animals would appear to lack much that other subjects of study have, but that is not necessarily the case. Even if all the lower forms of life had been completely identified and studied, there is still much investigation to be done as to their behaviour under varying conditions and their inherent variations. Actually we are still far from a complete knowledge of all forms of life and have only touched the fringe of the problem of how stock—animal or vegetable—can be improved by selection. Furthermore, these sciences are no longer confined to the laboratory, but spread their research out into the natural habitations of their subjects. Zoology also has had a great development as a comparative subject

and links up in this way with archæology and the study of the development of mankind.

This linkage of different sciences is emphasised in the case of astronomy. It is true than an astronomical observatory cannot be compared, structurally, with other laboratories but the methods employed, the exactitude necessary and the type of mind needed for the work all link it up with other sciences. It is no longer—has not been for a long time—a question of observing the stars. Astronomy has joined with chemistry, and through a medium such as the spectroscope can tell us the composition and probable age of the stars it studies. On the other hand, using the most advanced methods of mathematics it covers all the questions of the size and nature of the universe; and leaving science behind tries to solve the problems of higher philosophy.

There are at every university, laboratories in engineering, in electricity, in metallurgy, in geology and so on which we shall discuss with those sciences we have to consider in relation to industry. As a rule they work in close connection with industry and industrial problems and combine both the functions of preparing students to staff commercial laboratories and of doing absolute research. There are other laboratories not connected with industry but which are closely concerned with everyday problems;

these are the laboratories of the medical sciences, the pharmaceutical laboratory where new drugs are purified and tested, and the physiological department where the normal functioning of the human body is investigated. In the history of medicine many discoveries as to normality have been made possible by observations on occurrences in the body during disease or under the influence of other abnormalities. The physiological laboratory is therefore often in close relation with the pathological department where the abnormal and disease processes are studied.

It is the pathological laboratory and its relation to human life that we are going to discuss in greater detail, but there are two links with other phases of human life we must mention here. The pathologist, from his knowledge of the human body after death, has become closely associated with the detection of crime, especially of crimes of violence. Not only is the pathologist able to give the exact cause of death, but he is often able, by describing how that cause must have operated in any particular case, to indicate which of certain probable theories is most correct.

The second of these links connects pathology with all the sciences trying to elucidate the story of man's development. The archaeologist has been able to make some quite remarkable deductions from evidence as to how the people, whose skeletons he discovers, died, and the

disease from which they suffered. The bones show evidence of a comparatively small number of diseases, and had the soft tissues been preserved we might have acquired much information as to the lives of our ancestors.

Nowhere in absolute research does one subject stand entirely isolated from another. Problems arising in one, and seemingly insoluble by the methods of that subject, may yield to methods borrowed from another field. When we come to look into industrial laboratories we find that this need for overlapping is even greater. Nothing is so astounding in modern industry as the number of different types of processes that contribute to the industrial machine. The machinery of one type of factory will show many ideas borrowed from machines in another factory doing different jobs. The lathe of the engineer is modified for new functions in a cabinet factory; the machine which turns out cigarettes at many hundreds to the minute contains its own printing-press; a modern plant for packing tea not only makes the packets but weighs the tea in a balance which depends on the electrician for its remarkable accuracy.

The result of all this is that the industries which really do make use of the laboratory may require to employ workers who are expert in fields not obviously connected with the industry.

The textile industry is a notable example of this, for the manufacturing processes of industry have undergone such a rapid and revolutionary development that in many instances the laboratory worker appears to have taken control. All the vast number of new materials now appearing in the market come, fundamentally, from chemical research. Cellulose and all its derivatives has been developed by chemists and their production requires very exact chemical control.

While the chemist has been showing how these materials can be produced, the engineer has had to face the problem of designing machines to handle them in saleable quantities.

Despite these new developments the materials which man has for centuries used as textiles, wool, linen, cotton, are still being produced and the scientist has been giving them attention also. It is not only that he has been showing how production can be both standardised and made more speedy—in that direction the advance has been phenomenal—but the scientist has also been inquiring into the why and wherefore of processes that are age-long. It is now realised that bacteria, which we know are almost universally present in nature, enter into many industrial processes; the preparation of leather, for example, is hastened by the presence of certain bacteria. Long before germs had been rendered visible to man the tanner had learned

that certain processes were beneficial if carried on for a certain time and then stopped, but that they would be harmful if allowed to go on too long. The bacteriologist now shows that the beneficial process is due to germs feeding on the leather and so softening it, and further has shown that the process can go on to destruction of the material. This knowledge has enabled scientific control to replace the rule of thumb, though often efficient, traditional methods.

The woollen industry has also been forced to recognise the presence of bacteria in its raw materials and its finished products, for germs, especially mildew, can do almost incalculable harm in woollen cloths. Bacteriologists have now shown how to control these "diseases" of wool—a difficult process, for the chemicals used must not interfere with the dyeing processes or harm the manufactured product in any way. The chemists had to be brought into the investigation here for it was necessary to prepare new chemicals.

The chemist of to-day is constantly being asked to tackle problems of a similar nature. It has been found, for example, that a certain chemical has some properties that are desirable, but others that are harmful; can the chemist make an alteration in the chemical substance which will eliminate the harmful effects, leaving, and if possible, enhancing the desirable results? Strange to say the chemist usually can. It may be a long

and sometimes uneconomic process, but given time the chemist usually can discover the perfect variation of the substance first examined.

We have already mentioned how Ehrlich worked through hundreds of arsenical compounds in his search for the ideal anti-syphilitic, and the same story could be repeated for other remedies. For example, chemists everywhere are seeking the perfect anaesthetic, and many new drugs have been made and tested. Anaesthesia has been an enormous boon to mankind but it is not yet a standardised process, nor absolutely safe and certain. Working on the various derivatives of certain chemicals long known for their soothing effect on the nervous system, the chemist has in the past few years given the medical world a great variety of drugs with anaesthetic properties. One of the latest, injected into a vein, produces in a few seconds a complete loss of sensation which lasts about twenty minutes but leaves the patient with no ill effects.

All this is only a small part of the work chemists are doing in modern industry. There are certain manufacturing processes which depend for their existence on purely chemical processes and every employee is to some extent a chemist. A firm engaged in making analytical and pharmaceutical chemicals must employ a large number of qualified chemists both for control of its products and for the discovery of new substances and new

and more efficient methods of manufacturing chemicals. But even in a chemical factory the scientist may have to utilise the knowledge of other sciences. The pharmaceutical chemist makes many products which can only be standardised by their effect on animals, and this may involve quite elaborate tests. Thus the insulin made in this country, which saves the lives of so many diabetic patients is tested by a hundred tests on rabbits before being sold. Only by this means can each batch be guaranteed as absolutely up to standard.

The chemist has to control manufacturing processes of which the end products are not chemical but which require the application of chemical tests of a very difficult nature at every stage of manufacture. Oils and petrol, the source of so much power in the modern state, have all to be tested, blended and re-tested before issue to the public. The larger petrol firms in this country exercise a most careful control of their products and employ many qualified chemists. Oil and petrol do not allow of the same type of chemical analyses as simpler substances and many of the tests are functional tests; that is to say if the substance, under pre-arranged conditions, behaves in a certain fashion, it can be regarded as corresponding exactly to the necessary standard.

Rubber also requires most careful control and

it is also a substance which can be more readily tested as to its behaviour under certain conditions than as to its exact chemical nature. Rubber is used in a thousand ways in modern life, and it is only kept standardised and efficient by a careful watch on the raw materials. The chemist has found so many uses for rubber and so many ways of preparing it that it is difficult to picture civilisation without it. The chemist is, however, not yet satisfied, and while he thinks out new ways for utilising the natural raw rubber, he is trying to find a way to reproduce it artificially.

Chemistry is also the controller of the great industry built up round the photographic camera: The present-day photographic plate and film are the result of much chemical research. The discovery that certain chemicals could be so influenced by light as to give an image of people and things was an astonishing find, but even after years of work on it the chemist has not managed to reach any finality on the subject. He is always experimenting to improve and to speed up photographic materials and methods. The latest development, and one of the most interesting, is that of the "infra-red" plate which permits of photographs being taken not only at very long distances but in places where the light is so poor as to be, in ordinary human eyes, apparently completely absent.

The mining and coal industries make an ever

increasing call on the scientific world; coal-mining is beset with almost innumerable difficulties some of which are at last yielding to scientific research. There are the questions of applying mechanical methods to various stages of coal-getting and of lighting the underground workings. Light not only simplifies the actual handling of coal and machines but it is also the best preventative of miner's nystagmus, a disease in which the eyes are affected. But a lighting system in coal mines requires to be of a very special type, for not only must it withstand conditions not met with above ground, but it must also be so made that it cannot give rise to electric sparks. The greatest danger in a pit is an explosion of gas or fire-damp and these can be caused by even the smallest electric flash or any naked flame, so that all lighting systems must be designed to meet this danger. The Safety-in-Mines Research Board has shown many ways in which these dangers can be mitigated, and at Buxton has an apparatus in the shape of a steel tunnel in which underground conditions can be reproduced for test purposes. But once the coal has reached the surface the scientist really gets his chance, for coal and its derivatives provide an amazing variety of chemical products. It is even suggested, and not entirely as a joke, that some day everything we need for life will come from coal. At present medicinal drugs, poisons, dyes

of every hue, oils of all grades, petrol, illuminating gas and fertilisers for the soil, all arise in the process of using coal for power production. To most people the latter is the primary function of coal, but we are really on the verge of a new era in the utilisation of that valuable mineral. The wasteful domestic fire, which may give as low as ten per cent. of the available heat stored in coal—cannot compete, for example, with the efficiency of electricity produced by the agency of coal burned in boilers, where nearly ninety per cent. of the heat is utilised and innumerable valuable by-products retained.

In passing we may observe that the whole problem of domestic heating can only be solved when the work being done by places like the Building Research Station at Watford have told us more about the materials available for building purposes. It seems probable that, in the future, houses will continue to use a combination of smokeless fuel, electricity and gas for the purpose of giving light, heat and power. But we have still to learn much about ventilation and the heat-retaining powers of building materials, while it is impossible to ignore work being done in connection with the effect of light and heat rays on the health of the human body.

Agriculture utilises science in nearly as many ways as the coal and gas industries. Man has accumulated a surprising amount of knowledge

about the soil and the need for a proper rotation of crops, and the use of fertilisers, and farmers have been able for generation after generation to keep the productivity of their farms at a consistently high level. But now the scientist by observation and experiment is showing not only why these results were obtained, but how they can be improved upon. Rust resistant wheats and wheats that ripen ten to fourteen days earlier than the parent stock, form the foundation of Canada's wheat industry, and these have been developed by patient experimental labour. That work is still going on and it seems likely that new strains of wheat seed will soon be available for every type of British soil and capable of giving a high yield under our climatic conditions. In similar ways the quality and quantity of fruit given by British orchards has been much improved by a better selection of fruit-bearing strains and of the stock on which they are grafted. The latter has been shown to be of more importance than was at one time thought to be the case and fruit growers can now look forward to a high standard of fruit from orchards in England.

There are men working on the improvement of seeds and of the fertilisers needed for them; research in these subjects being done partly at state-subsidised farms and partly by chemical manufacturers. There are stock-breeders who are

showing how the qualities of any particular species can be altered to suit man's needs. Everywhere research workers are investigating animal disease, and veterinarians are striving to get rid of those diseases affecting the domestic animals—a problem of importance in public health, as so many of these illnesses can be transmitted to man. We are likely to see an almost continuous increase in the importance of veterinary work in this country, and the number of veterinary surgeons is far from sufficient to meet the demand.

There remain for brief consideration a group of industries in which laboratory careers are open to those trained in a variety of sciences. All the engineering industries now employ scientists of one type or another, and, closely allied, are the experts working in mineralogy and metallurgy. The latter science has provided in recent years many new metals: alloys of steel with various hardening and strengthening components and also non-ferrous materials with a multiplicity of functions. Many of the new methods of employing metals have meant full investigations into the basic structure of different elements, and a special technique has been worked out so that by means of X-rays the crystalline nature of metals may be observed.

Much of the development in metallurgy has been associated with advances in the electrical

industries. Certain rarer metals and alloys play an important part in electrical products, and lately the rarer gases have also been employed. Everyone is familiar with the blue and red electric signs which make use of the rare gases neon and argon as paths for the conduction of electricity. There is not space to consider all the developments in the most modern of electrical industries, wireless; here we have a new science still in its infancy and the possibilities for scientific discovery in this field are limitless.

In discussing all these questions it must be understood that we are using the term laboratory in a very wide sense: there is no industrial research which does not utilise a laboratory—such as we will describe in detail—to some extent, but many of the research and control departments bear no very close resemblance to the conventional idea of a laboratory. The men who spend their lives "tasting" tea speak of their testing room as a laboratory, though the method of tasting tea for blending purposes remains an art rather than a science. Those experimenting with electricity in powers of the nature of one million volts work in a laboratory which gives one something of the impression of a cathedral, with its high roof and great column-like transformers. Testing of ships in water-tanks at the National Physical Laboratory or of aeroplanes in wind-tunnels at the same place, require a vastly differ-

ent type of building and technique from that needed in testing the efficiency of a thermionic valve, or the observation of a hitherto undescribed microbe. But, throughout, the same attitude of mind towards the problems, the same care in the making and handling of apparatus, and the same painstaking observations and accurate recording of results, are all needed if the desired goal is to be reached.

CHAPTER IV

The Rewards of Research

It is a strange anomaly of modern life that men who are engaged in work that may be of vital importance to the nation as a whole, often receive a financial reward much less than that paid to people in other walks of life. The man who makes a vital discovery in regard to disease prevention will certainly receive a salary that is in no way comparable with that of an actor or film-star. It is exceedingly rare for a laboratory worker to receive an income such as the amount of care and responsibility he must assume would win for him in commerce.

It is said, of course, that the laboratory worker has such satisfaction from the results of his work that he does not look for—should not look for—any great financial fortune. The position is now arising that, as the scientist becomes more and more important to industry and health, he feels justified in expecting not only a secure financial position but a position secure from other drawbacks of commercial life. He expects freedom from many of the ordinary rules of factory and office,

freedom to work on his own problem without hurry and without any feeling of compulsion to produce results.

These conditions prevail to a large extent in academic laboratories. There is, of course, a general control which ensures that any routine work of the laboratory is done speedily and efficiently; and the research worker is expected to show zeal even if his results do not prove of exceptional value. On the whole he or she is free to work along their own lines. It cannot be said that the financial reward is greater in either the academic or industrial field. Certain industries do pay their research workers larger sums than are paid to university professors, but they only do so when they wish to attract men of exceptional ability. In such a case the industry expects to get a "return for its money" in the form of results of commercial value. The industrial scientist is one cog—even if really important—in the machine, and he has to work at the tempo of the whole machine. Should he make any discovery of value, that discovery belongs neither to himself nor to the scientific world, but to the firm that employs him. If it is patentable, the rights belong to the company.

There is still a feeling in the scientific world that those doing absolute research are of higher status than industrial research workers. It is possible that this arises partly from this question

of freedom to publish results. In academic laboratories on the other hand, a man's results belong to himself or to the world. There are cases where the governing body retains a control over publications, but in most research laboratories of this type all work done finds its way into the scientific journals.

Industrial scientists do, of course, publish their results in these journals and at least one big electrical concern in this country publishes its own journal. It is a fairly general rule in industry that results either already protected by patent or which are recognised to be of general interest or absolute scientific value, should be published in the journals of the science in which the results have been obtained. Scientific societies abound, and workers in industrial laboratories are usually encouraged to attend them and to discuss their own and other people's results.

In this way the worker in absolute research at a university meets the worker in industry, and the exchange of ideas is mutually beneficial—there is no question that both have much to give the other. At one time the flow of scientific knowledge was from the research laboratory, through a variety of channels, to industry, but now there is a steady stream of results, suggestions and requests for information flowing back to the research institute from the industrial field. The man or woman of exceptional ability has therefore in this

way a chance of establishing a professional reputation no matter in which type of laboratory he or she is working.

Academic honours are not confined to either type of scientist and many workers in industrial laboratories hold the highest possible qualifications. Indeed there is one advantage the industrial laboratory holds over the university institute. The technician who joins e.g. a medical laboratory in a university school very rarely proceeds to take an academic degree and so become a qualified worker in his subject. In the industrial laboratory, however, those who enter after matriculation, or having passed the Inter-B.Sc. stage, usually continue their studies and many proceed not only to their B.Sc. but to higher degrees.

Before leaving the subject we should remember, as indicating how much the obtaining of results means to those of scientific tendency, that there are a very large number of amateur scientists in the country. People enter the scientific profession for a variety of reasons and it appears that many more would do so if possible. The meteorological department, for example, gets reports of weather, growth of crops, occurrence of storms, etc., from a very large number of amateur observers. Ornithology owes much to bird watchers everywhere. Wireless, it is no exaggeration to say, would not have advanced

even as it has done were it not for the work of amateurs. This is particularly so in the case of short-wave transmission.

To sum up, we may say that none of the scientific positions offer a man much opportunity of a large financial reward and there is not much to differentiate the commercial from the academic post in this respect. But to men of any ability there is usually security and an opportunity for original thought and method. The grappling with a variety of problems and bringing them to successful conclusions makes even the control laboratory of a factory a place where a man can do good work without that feeling of boredom so common to routine industrial processes.

CHAPTER V

The Pathological Laboratory

So far we have been speaking of laboratories in a general sense but it is now necessary to take one type of laboratory and describe it in detail. To the public mind the most important laboratory is probably that connected with human health and disease and it is the pathological laboratory we must examine more minutely. Pathological departments form a very large group of laboratories, for, apart from a number privately owned, every hospital of any size and every university has such a laboratory. Pathology is the science of disease and the term will be used here in that general sense. Disease is not a single process nor is it caused by only one agent, so that the problems in pathology can only be solved by calling in workers trained in different sciences. Many of the methods used are borrowed from other fields and adapted to the investigation of human ailments.

Three main branches of the subject are usually recognised. The first is bacteriology, the science of bacteria, in which the germs causing disease

are studied and identified. Secondly there is bio-chemistry in which the chemical constituents of the body and the changes they undergo are investigated. Thirdly there is histology, the science of the tissues. The term does not necessarily apply to diseased tissues but is used here in that sense.

Each of these branches of pathology is a large and still expanding subject so that some degree of specialisation in one branch is usual. In the academic institute there is always a complete splitting up of the work so that each subject has its own laboratories and its own workers. In smaller hospitals the worker in pathology is expected to show a knowledge of each branch, and his work really constitutes a fourth division of the subject, clinical pathology. He is concerned with the direct application of the subject to the sick, and his work is mainly of a routine nature.

Those in control of pathology laboratories are always medically qualified, a knowledge of the whole subject of medicine being necessary to the comprehension of the problems involved. Most of the scientific workers in this subject are medically qualified, although in bio-chemistry there is sometimes an opening for the pure chemist. Pathologists constitute a comparatively small profession in this country but one of high importance.

Outnumbering the pathologists are the laboratory assistants or technicians. Until recently the technicians in pathological departments have only rarely been academically qualified. The method of recruitment was formerly to take boys from school and to train them in the methods of the laboratory. They rose by stages to the most senior position which carries a very considerable responsibility. Recently it has been found possible to obtain university graduates willing to do this work and graduate-technicians are becoming more common. So also are those who hope to qualify by attending evening classes.

Laboratory technicians, as we have already mentioned, are not organised in one body, but the assistants in pathological laboratories have long had their association, which at present has about one thousand members. This association has a variety of functions, probably the most important being the issue of diplomas. In this work it is aided by prominent pathologists, and most technicians now endeavour to take the certificates in each branch of the subject.

The technicians in the pathology laboratory carry out all the processes necessary for preparing materials for examination and carry out certain tests. The exact degree of responsibility given to them varies in every laboratory, but there are a large number of tests now done entirely by the technicians. The correlation of the findings with

the condition of the patient is the work of the clinical pathologist.

The technician of to-day has been responsible for many improvements, particularly in detail, of the methods in use. A skilled technician usually works out his own way of tackling each problem, and sometimes these are worth passing on to other workers; this is done through their own journal and at regional meetings. The technician should be no less interested in his subject than the pathologist, but that interest is more in the attainment of results than in the application of those results.

In referring to the technicians as though they were all male one may give a false impression, though that is the conventional way of writing. There are many women technicians and those people who are joining laboratories after graduation are largely women. The fact that they have a general training enables them to assimilate the methods of pathology more rapidly than the ordinary boy who joins at an early age. One large public body has lately appointed about twenty such women who after six months' training, are put in charge of a small laboratory, and the method seems successful.

The technician has a variety of work to do and usually has in his turn an assistant who does the washing and cleaning of the apparatus, chiefly glass-ware, used in a pathology department. In

bacteriology he has to prepare the media necessary for the growth of germs and he has to handle these germs as they are put through the tests necessary for their identification. His position is therefore not without danger—there have been cases of technicians acquiring disease in the laboratory—and he must learn to protect himself against these bacteria. The knowledge of methods of sterilisation is the foundation of his own safety, as it is of the routine work in bacteriology.

CHAPTER VI

Some Routine Problems

The human body is a particularly complicated mechanism and is liable to suffer from a great variety of derangements and diseases. The pathologist is constantly seeking new ways of tracking down disease and its causes and there are now many tests available for the exact determination of certain diseases. The pathologist's work is therefore divided into seeking new facts about disease and new tests for its diagnosis, which is research, and applying recognised tests to particular patients, the usual routine work.

It may be necessary for him to see the patient himself but the greater part of the work consists of the examination of specimens from the patient. Before any specimen reaches the pathologist it has to pass through a number of hands. The routine machinery of all laboratories requires a clerical staff and a regular system of keeping records and reports. The specimen has to be received and registered and is usually given a number by which it is known throughout whatever tests are needed. It must be accompan-

ied by a card or form indicating what tests are to be done and having space for the reporting of results. These have to be typed, sent to the wards and copies filed and indexed.

In bacteriology the main problem to be solved is the isolation and recognition of germs recognised as causing disease. The doctor in charge of a patient may have made a fairly firm diagnosis that his patient is suffering from a particular bacterial disease but he calls in the laboratory to prove that the organism is present in the body of the patient. Thus the suspicion that a child has diphtheria in its throat calls for the dispatch of a swab from the infected part to the laboratory where the *bacillus diphtheriae* can be recognised. A patient who shows signs of tuberculosis of the lung has usually a cough and sputum and in the latter the bacteriologist can demonstrate the tubercle bacilli. Typhoid fever is one of a group of infections due to closely related germs which occur in the alimentary tract, and to obtain an exact diagnosis necessitates the isolation of the organism.

The identification of organisms is a modern science for it is only during the last seventy years that the importance of germs to mankind has been realised. Germs are such infinitely small things that the first thing necessary for their recognition is the microscope by means of which small objects can be magnified many hundreds

of times. The compound microscope is itself the result and the object of much research and the modern instrument enables all germs above a certain size to be recognised clearly and quickly.

The shape and size of a germ is not, however, always sufficient for identification purposes and it is therefore necessary to grow the microbe so that other tests can be applied to it. Germs are grown, in the laboratory, on a variety of substances, the simplest of which is a clear broth made from heart muscle and stiffened with gelatine or agar-agar. The latter is solid at body temperatures. These substances when prepared are called "media" and they must be prepared, by heat sterilisation, in a form free from other germs and placed in sterile glass containers. A simple medium is not always sufficient because some germs will only grow when given fairly elaborate foodstuffs.

Having grown one's microbes, one has to prepare them for examination under the microscope. Most microbes are colourless and translucent so that they are not easily seen under the microscope. It is therefore necessary to colour them and this is done by smearing the germs on a piece of thin glass and colouring them with a dye. This may be a simple process or it may be quite elaborate as in the case of the tubercle bacillus which does not behave like any other germ.

Germs are living creatures and therefore require foodstuffs like all other living things and certain tests are based on the fact that most germs use a quite restricted number of chemical substances as food. There are a very large number of sugar-like substances, quite closely allied chemically. These sugars can provide food for microbes, but it has been found that a germ will utilise one sugar and not another, while a quite closely related germ will do exactly the opposite. On this basis has been built up a technique by which the reaction of germs with their sugars can be observed.

The methods developed for bacteriology have, of course, no place in the bio-chemistry department. Here the problems are similar to those of the chemist elsewhere but the fact that tests are being done on products of the body, especially blood, introduces a number of difficulties. The most commonly adopted methods of the modern clinical bio-chemistry laboratory depend on colour reactions, either for direct comparison or by comparison in a colorimeter, an instrument which enables the degree of agreement between colours to be measured. It follows that the natural red colour of blood would interfere with these results so that special methods have to be devised for getting rid of the colour and obtaining a clear solution of the chemical constituents of the blood.

A still further series of tests and pieces of apparatus are needed in the histology laboratory. Here human tissues have to be prepared for microscopical examination. The tissues are too solid for inspection by transmitted light, the usual illuminant for the microscope. To enable this to be used, the tissue must be cut in exceedingly thin slices and fixed to glass slides. This is managed by first embedding the specimen in paraffin wax and cutting the slices on a microtome, an instrument fitted with a very sharp razor and so adjusted that large numbers of sections of the tissue can be cut, all of exactly the same thickness a few thousandths of an inch. These are fixed to glass slides and after removal of the paraffin wax, are stained with a combination of dyes which shows up every detail of the structure of the tissue.

In ordinary work one combination of colours is usually found sufficient, but for special examinations and for certain organs, especially the brain, other methods are needed. The most interesting are those in which the tissue is soaked in a solution of silver or gold salts. Only certain cells take these up and by a method somewhat analogous to the development of a photographic plate, these cells are made to show up very distinctly.

A subsidiary part of the work in the histology laboratory is the preservation of diseased organs

and their preparation as museum specimens. The most common method, which allows of a restoration of the original colours, is to attach them to glass plates or rods immersed in a solution of glycerine and hermetically sealed. Such specimens are not only a record of unusual conditions but are also of value for teaching purposes.

Histology has been of immense value in man's quest for knowledge of the human body. Anatomy first recognised the different organs of the body and tried to correlate their size and shape with their most obvious function; but histology showed that the organs are composed of microscopic cells, and was able to indicate what part they played in the normal functioning of the organ they composed. In the pathological laboratory the histologist is not concerned with the normal function but with departures from normal and he is able to identify many disease processes. The methods of bacteriology may be called in, for it is in many cases possible to prove the presence of disease-producing germs in the tissues; this is indeed one of the most important links in the proof that germs cause disease.

Thus the tubercle bacillus can be shown in tissues that give the typical appearance of tuberculosis. As already mentioned it requires a special method of staining which permits of no doubt in identifying it. It can be grown on artificial media from such tissues, and, as we shall

explain later, if introduced into other animals will again cause the appearance of diseased tissues, giving the typical histological picture of tuberculosis.

Specimens may, of course, require tests to be done in more than one department of a large laboratory. Everyone knows that the brain and spinal cord are bathed in a protecting fluid, the cerebro-spinal fluid, which normally has a certain composition. When brain disease is suspected this fluid can be withdrawn by putting a needle into the back so that it passes between the bones and pierces the covering of the spinal cord. A complete examination of this fluid will be very valuable in diagnosing the condition; a complete examination necessitates examining it for the type and number of cells, the presence of germs and the chemical composition.

In this way the work of the various departments overlap and are related. In a laboratory of this type the experts in charge may be required to apply such a variety of tests and to use so many methods that they must have a very wide field of knowledge. The specialist in the research laboratory seldom attempts to cover more than one or two closely related problems. In the routine laboratory the pathologist requires to range over many sciences and adapt suitable portions of each to his great problem—the diagnosis of disease in actual cases.

CHAPTER VII

The Laboratory and the Patient

In the pre-laboratory ages medicine was almost entirely an art. Faced with sick people, the physician, having made what examination he could, formed his opinion as to the nature of the disease present from his experience rather than from a recognition of the disease processes going on in the patient's body. The whole of medicine has of course advanced in the last century, and, although observation coupled with experience should still play the major part in the diagnosis, the physician of to-day has a clearer picture of disease and can make much more exact and detailed examinations.

Having formed his opinion in any actual case that the disease is this or that, he may be able to add more exact knowledge by means of laboratory tests. It is true, as we shall see, that even in that connection, experience and ability to draw the most probable deductions, still play a part, but there are certain tests where the result can be taken as absolute proof of the diagnosis. Nevertheless, it is not possible, as in a purely research

laboratory, to divorce the laboratory findings from those of the physician and surgeon and the clinical pathologist must be in close contact not only with his medical colleagues but with his patients.

The clinical pathologist draws his deductions from the examination of the normal or diseased products of the human body. Few diseases occur without causing widespread changes in the body—especially in the blood—which may be detected by laboratory methods; and many diseases cause the production of abnormal products, sputum, pus, etc., which can be examined. When these products can be collected they are sent to the laboratory with a request for information on the point at issue, but there are certain tests which the clinical pathologist does himself on the patients, and certain specimens—chiefly blood—which he collects.

Bacteriology yields very accurate results in certain cases. We have already mentioned the discovery of the tubercle bacillus in the sputum. All forms of tuberculosis are caused by the tubercle bacillus which has the staining reaction, already mentioned, that marks it off from all other usual disease-producers. In sputum, from tuberculosis of the lung, in pus from almost any organ, in urine from tuberculosis of the kidneys and in cerebro-spinal fluid from tuberculous meningitis, thc tubercle bacillus can be found.

Their presence leaves no room for doubt as to the nature of the disease.

Other organisms cause definite diseases and can be isolated in the laboratory. The typhoid and dysentery organisms can be found in the excreta, and by similar methods germs causing certain cases of food poisoning can also be isolated. This requires a special technique, for the excreta consist so largely of organisms that the isolation of any particular type is a matter of considerable difficulty. The organism may sometimes elude discovery altogether but bacteriology is not, therefore, completely defeated. By means of a test known as the Widal reaction, the cause of the disease may still be proven.

When a person suffers from typhoid or one of the related fevers his blood reacts against the infecting germ. This can be clearly demonstrated by mixing some of the clear serum, obtained by allowing some of the sick man's blood to clot, with a suspension of the appropriate germs. If the blood contains the antibodies produced by the body in its fight against the disease, it will cause all the germs to adhere together in small clumps. This process of agglutination, as it is called, is a most valuable diagnostic test and clearly indicates the microbic cause of the disease.

The same phenomenon has in recent years been utilised to diagnose cases of a disease known for a long time to occur in animals but not

previously considered to affect mankind. An organism called *Brucella Abortus* is a very common cause of disease in cattle. Its worst effect is that of contagious abortion in milk cows and the germ is to be found in a very large number of samples of milk. It follows that there is ample opportunity for the germ to infect man and many cases have now been discovered in this country. In town dwellers milk seems to be the only source of infection although it appears that in men working with cattle the germ can enter the body through the skin. Patients infected in either way suffer from a feverish illness which usually lasts for many weeks but is fortunately very seldom fatal. During the fever the germ can be isolated from the blood-stream but the more common method of diagnosing the condition is by mixing the serum with an emulsion of the organisms and, as already described, observing their agglutination. The disease is closely related to Malta fever, which is due to a similar organism, the *Brucella Melitensis* which is a natural cause of disease in goats. Abortus or undulant fever, as it is called from the nature of the illness, is of increasing importance on account of its widespread occurence among milk cows but it has been shown that pasteurisation completely destroys the germ.

The reaction of the body to different germs is a particularly exact process and the antibodies

produced only react with the organisms that called them forth. There are certain germs so closely related to each other, such as those called *Bacillus Paratyphoid*, A, B, and C, which the ordinary cultural tests cannot distinguish but which nevertheless call forth quite distinct antibodies. It is, in fact, by making use of this fact that these organisms are distinguished, the unknown organisms being mixed with serum containing antibodies of one type only. A resulting agglutination shows the organism to be of that type also. So far these antibodies are outside the range of chemistry and are only known to exist by their effects on bacteria.

Chemistry, however, gives exact information about sick people, especially by examination of the blood. The blood is the great transport system of the body, for by means of it all the foodstuffs, oxygen and waste products are carried from organ to organ. In normal health the body is so adjusted that the chemical composition of the blood changes only within narrow limits. The digestion of food may load it with certain substances, e.g. sugar or fat derivatives, but it very quickly deposits these in various organs and returns to its normal level. Prolonged research and collection of statistics has given us a fairly exact knowledge of the limits within which the chemical composition of the blood normally lies.

Blood is taken from the veins of the arm and sent to the laboratory either as clotted blood or mixed with such a substance as potassium oxalate which prevents it coagulating. In certain large laboratories it is the habit to carry out a fairly elaborate chemical investigation on each sample, but the more usual practice is for only those tests thought to have a bearing on the case to be done. For example, if a patient is thought to be suffering from kidney disease, the blood is examined for urea. This substance is always present in the blood and is a by-product of protein utilisation. It is normally filtered off by the kidneys and excreted in the urine. If the kidneys are damaged by nephritis the amount of urea they can handle is diminished and so it accumulates in the blood. There are a number of methods available for estimating how much is found, and if more than the normal figure, it indicates that the kidneys are definitely damaged.

The chemical examination of the blood that is probably best known is that for sugar which is so important in diabetes. Sugar is the great provider of energy to the muscles and is normally kept at a constant level in the blood by an interaction of the liver and the pancreas gland. The kidney does not excrete sugar unless it reaches a very high level in the blood, which is the case in diabetes. There are a few cases, however, in which the kidneys do not function normally, but allow

sugar to pass at a low level. The discovery of sugar in the urine is therefore not an absolute indication of diabetes; a test carried out on the blood will demonstrate the true condition without fail.

The substance which controls the sugar level—insulin, as it is known—is secreted by a particular type of cell in the pancreas gland. It is interesting to note that it is possible for there to be too much of this substance produced, so that the sugar in the blood falls to a level so low that life is no longer possible. Such a condition is exceedingly rare and is usually due to a tumour occurring in the pancreas, and in this country only two cases are known to have occurred.

Other chemical constituents of the blood are estimated and although not commonly deranged may be of great importance in certain cases. The blood, to take an example, contains a very small amount of calcium (lime) and recent work shows that it is very difficult to alter the level of this either by the administration or withholding of calcium. If found to be altered the result is of considerable diagnostic influence. A case recently reported was that of a girl whose bones were so brittle that the slightest touch caused them to fracture, with the result that all her limbs had been broken and deformed. Examination of the blood showed a calcium figure much above normal, indicating that she was actually destroying the calcium of her own bones. This, it was

thought, could only mean that the parathyroid gland which controls the calcium was overworking and was probably enlarged. An operation revealed a tumour of the gland and removal of this caused a complete disappearance of the trouble and a return to normal of the blood calcium.

In the bio-chemistry department, the ordinary methods of chemistry are used with only slight alterations, but the clinical pathologist in other tests utilises methods peculiar to the subject. The examination of the blood cells is one of the chief diagnostic aids and requires methods not directly derived from any other science. Blood consists of a clear yellow fluid, the plasma, in which float the blood corpuscles; these are solid bodies composed of protoplasm, and are actually living cells. They are of two chief types, the red cells and the white cells; the red corpuscles are small bi-concave discs and contain the hæmoglobin which carries oxygen from the lungs to the tissues. Red cells are so small that 3,500 of them side by side would only measure an inch. There are five to six million of them in a cubic millimetre of blood, "that is to say there are more red cells in one drop of blood than there are people in the United Kingdom." The white cells which are a little larger, number about 7,000 per cubic millimetre and can be sub-divided into smaller groups. All have a nucleus which varies in size

and shape; their chief functions are connected with man's fight against bacterial disease.

The blood may itself be the seat of disease or it may reflect disease processes in other organs. In either case it will show a departure from normal, and it is on the observation of these variations that the clinical pathologist bases his opinion as to the disease present. To make these observations pathologists have had to devise methods of accurately counting the numbers of red and white cells present.

The most easily illustrated variation is that known as anæmia in which the patient has fewer red cells and less hæmoglobin than normal. Blood for examination is obtained by pricking the lobe of the ear or the finger and is taken up into small but accurately measured glass pipettes. It is diluted with preserving fluid and this mixture is transferred to a "counting-chamber" in which by means of a microscopic ruled square the number of cells in a cubic millimetre can be counted.

The number of cells may be grossly diminished —people can still live with less than one fifth the normal amount—but in addition the cells may contain an amount of hæmoglobin less than normal, so that this substance has also to be estimated. A measured quantity of blood is added to water and compared against a standard. When this figure has been obtained a factor

called "the colour index" is worked out and serves as an indication of the amount of hæmoglobin in each cell. Related to the quantity of hæmoglobin in each cell is the question of the size of the cell; the normal red corpuscle has an almost exactly circular outline and the size varies very little. In disease the shape and size may show very wide variations: This is an important observation for, roughly speaking, the diagnosis of pernicious anæmia depends on the fact that the cells not only vary widely, but have an average diameter greater than normal. Pernicious anæmia is a disease of the blood itself and is spoken of as a primary anæmia, while forms of anæmia due to other diseases are said to be of secondary type. It is important to know which type one is dealing with, for while the latter may yield rapidly to the administration of iron, the former can only be successfully cured by giving liver or liver extracts.

The size, shape and general appearance of the red cells is best studied in a preparation of dry blood. This can be made by spreading out very thinly on a glass slide a drop of fresh blood. This film is then stained with a special dye which also colours the white cells and makes it easy to see the type of nucleus which they possess. In normal blood the number of each type is fairly constant, but in disease they vary markedly so that a differential count is always valuable.

As with the red cells we may have a disease which is primarily of the white cells, or we may detect a change in these due to other abnormal conditions. In leukæmia the number of white cells may be increased enormously and a great variety of abnormal white cells may appear in the blood. White cells develop in the bone-marrow from primitive cells which normally do not pass into the blood stream, but in a leukæmia condition all stages of development from the most immature upwards may be found.

The most commonly looked for change in the white cells is one due to bacterial disease, especially those producing local inflammation. The change produced by germs is not always the same, and this, therefore, makes the test of considerable value. The two main classes of white cells are the polymorphonuclears, as they are called from the shape of their nucleus, and the lymphocytes. The latter are occasionally increased, for example in whooping-cough, but the polymorphonuclears are the most often affected. They are directly concerned with the destruction of microbes and an inflammatory or suppurative process in any organ at once calls upon them to assemble at the diseased place and fight the invaders. This means that the bone-marrow has to produce these cells in larger numbers, and the increase can be counted in the blood. Normally they form 65 per cent.

of the total white count, but in an acute inflammation they may reach 90 per cent. or over. The surgeon who is in two minds about any particular case may find the information given by such a count sufficient to justify an immediate operation.

Blood films such as are used to make these differential counts of the white cells have other purposes. There are a number of diseases due to the invasion of the blood by parasites of which malaria is the best known. There are a number of other parasites, the *Trypanosomes* and the *Filariae*, all conveyed to man by the bites of insects. These parasites circulate in the blood stream and can be seen in films of the blood. The malaria parasites invade the red cells, and in stained films all stages of their development can be made out.

We have mentioned that the blood cells float in a clear fluid, which is water with all the chemical constituents of the blood mixed in it. If blood, taken from a vein, is allowed to stand, it forms a clot and after a time this clot contracts and there collects a straw-coloured fluid, the serum. This can be examined in many ways—we have already mentioned the Widal reaction—and yields further information. Thus if the normal function of the liver is upset by disease there may be a retention of bile within the liver and this finds its way into the blood serum where it can be detected.

The test for which serum is most commonly used is that for syphilis, the Wassermann reaction. Syphilis is a disease of such widespread variation, occurring at all ages with different symptoms, and a laboratory test that really demonstrates its presence is therefore of unusual value to the physician. The Widal reaction, as is explained above, consists of mixing the serum with the actual germs causing the disease. The Wassermann, on the other hand, does not use the germ of syphilis or any actual products of the disease and is in a sense not a specific test. Nevertheless it has been shown over a period of years and through many millions of tests that a positive result is diagnostic of syphilis in almost 100 per cent. of cases. There are a few conditions, chiefly tropical diseases, which give a false positive result, but these are well recognised and so do not upset the validity of the test. The Wassermann is a complicated reaction in which the patient's serum, guinea-pig's serum, sheep's red cells, human heart muscle extract and a chemical called cholesterol are all mixed together and kept at blood-heat for a time. Put in that form it looks more like a piece of wizardry from the middle ages than a scientific test. In actual fact it is a development of many scientific observations, having a rational basis and giving very accurate and clear-cut results. It is now supported by the evidence of a great variety of modern tests based

on a different technique but giving similar diagnostic aid.

The clinical pathologist may come to the aid of the surgeon in one other way, through his knowledge of histology. If all cases could be diagnosed with absolute certainty the art of the surgeon would no longer be so important, but there are still large numbers of cases where neither experience nor naked-eye observation can give an absolutely correct answer. In these cases the surgeon may remove from the patient a small piece of tissue—for example a portion of a tumour or an ulcer—and ask the pathologist to state its nature. Sections, as already described, are cut and stained, and under the microscope it is usually possible to label the pathological process quite definitely. The surgeon is then able to decide to what extent further operation is necessary, and, in the case of cancers, whether he should give treatment with radium or X-rays.

Throughout all these investigations the clinical pathologist has but one aim, to give as much information as possible that will be of use in assisting the patient and his medical adviser to fight the disease that has attacked the human body.

CHAPTER VIII

Research in the Routine Laboratory

Since the clinical pathologist is pre-occupied with the diseases of actual patients it follows that his opportunities for research are largely limited to matters arising in the course of his routine work. When the clinical laboratory is large enough to be divided up in separate sections each dealing with one branch of the subject, there may be time to concentrate on more academic problems, but as a rule the clinical pathologist has to make his research develop out of the materials he has on hand every day.

For example in bacteriology the man working in a purely research laboratory may spend years on the detailed metabolism of a certain germ while to the clinical pathologist the same germ, represents a problem of detection in any particular case and the prevention of further cases. The worker in a research institute wants to know every recognisable feature of, shall we say, a food-poisoning bacillus, while the clinical pathologist wants to know how best and most quickly he can isolate that germ from the mass of bacteria in the intestinal tract.

Further limitations are, of course, imposed by the everyday questions of time and space. The purely research worker has no other problem but that in which he is engaged, and his laboratory has been designed to aid his research methods. In the routine laboratory there is seldom any space to spare and the worker is liable to find any research on which he is engaged interrupted by the urgency of his routine problems. Nevertheless, the clinical pathologist has, in another direction, ample encouragement to research, for through his hands passes all the material from actual diseases. It is from his preliminary observations that many problems have been recognised and passed on to the research institute; and it is through him that much of the material needed for more elaborate investigations is made available.

There is one type of research which the routine worker always has in front of him: the question of technical efficiency. There is a constant search for new methods by which tests can be done with greater accuracy or in a shorter time. If a patient's life depends on the answer to a certain test, it is no use employing a method which is not accurate, or takes days to do. The pathologist has often to compromise and adopt a method which is sufficiently accurate and which can be done rapidly. In this direction there is endless scope for advances and it is a form of

research in which not only the skilled pathologist, but also the laboratory technician can take a hand. So much of the routine work is done by the technicians without other control, that they have every chance to vary the methods in their search for efficiency.

In a recent publication a laboratory technician describes a method of estimating the cholesterol in the blood with a combination of accuracy and simplicity not previously realised. Cholesterol like the other chemical constituents we have mentioned is kept at a fairly constant level in the blood; its exact purpose is not yet agreed upon, but it is the clinical pathologists who have the best opportunity for correlating its variations with actual diseases. An accurate method in the past has meant an elaborate and lengthy process; now, chiefly by the ingenuity of a laboratory technician a more simple and equally accurate method is available.

In bacteriology the routine worker has always the chance of finding among his material some new type of microbe not hitherto identified as causing disease in man. There are many germs which occur so very occasionally that they tend to be regarded as accidental contaminants, and it is only when the pathologist's attention is attracted to them by a particular case that they receive sufficient attention to enable it to be settled whether or not they are the real cause of

the trouble. A recent paper described a new bacillus found in two cases of meningitis. This organism might well have been overlooked for it belongs to that group of germs which do not grow in the presence of oxygen but must be cultured anærobically. The occurrence of two cases closely following each other, however, made it apparent that this germ was of importance. Already other pathologists are on the look-out for cases and new light may thus be thrown on certain obscure cases of meningitis.

The clinical pathologist has often to come to the aid of his colleagues working in research institutes. This is especially so in the case of new curative preparations. A research laboratory or the laboratory of one of the large pharmaceutical firms may have developed a new drug and tested it by animal and other experiments. The final test can, however, be done only on human beings suffering from disease and this work usually passes to those pathologists who are actually seeing the cases. A very recent example of this is the development of preparations for the treatment of staphylococcal infections. The staphylococcus causes such simple conditions as boils but also very serious diseases such as abscesses of bones and treatment of these has in the past been chiefly surgical. Bacteriologists in various parts of the world have shown how an anti-body to these germs can be produced and experiments in

the laboratory show it to be of high potency. The stage has now been reached where the anti-serum can be applied to human cases and clinical pathologists are now testing what seems likely to be a very reliable remedy.

Technical improvements are always being made in bacteriology and the clinical laboratory shares the credit for them with the research department. Diphtheria is a disease in which the recognition of the causative germ in cultures made from the throat is of importance and in the past there have been difficulties in a certain number of cases. It has now been found that in the presence of certain metals, notably tellurium, the growth of most germs is inhibited while that of the diphtheria bacillus goes on uninterrupted. In addition, by a reaction with the tellurium a particular type of colouring is produced so that the germ is more easily isolated.

The Wassermann reaction in syphilis, as we have already mentioned, is about 100 per cent. correct in those cases in which it gives a positive result. But there are certain cases of obvious syphilis in which it fails to give the desired positive result, and this point has always worried the clinical pathologist. As a result he has searched for variations of the technique and for new methods likely to pick out these non-reacting bloods. It is now the almost universally recognised routine to back up the Wassermann with one of

these alternatives so that the chance of getting a result is increased.

All bacteria and all sections of tissue require, as we have seen, to be stained with dyes for their better examination. Some of the methods involve quite a number of different colours and the aid of chemicals which fix certain dyes and dissolve out others. Quite a number of the methods need an elaborate technique and the results obtained by different workers are not always comparable. The routine laboratory therefore is always ready to try out variations of the techniques employed and while certain comparatively old methods do not seem likely to be superseded, improvements are always taking place.

The pathologist often carries out research in conjunction with his clinical colleagues. When insulin was first made available for the treatment of diabetes every case in which it was used had to be controlled by laboratory estimations of the blood sugar. Clinical pathologists carried out very large numbers of these tests and so collected much information as to the action of insulin under a variety of conditions. This, correlated with the findings of the doctors in charge of the cases enabled the treatment of diabetes with insulin to be put on a scientific basis.

In pernicious anæmia, which we have already mentioned, the clinical pathologist has collected a large amount of data which has established the

diagnostic criteria for the disease. Now that it is so successfully treated with liver extracts, the clinical pathologist has an additional function, for it is necessary, by observing the response in the blood, to make sure that liver extract used is active. There is indeed an attempt being made to assay the value of new extracts by means of tests in new cases of the disease so that the extracts sold to the public may be of definite potency. Research has so far revealed no other method of carrying out this assay except by using the experience and technique of the clinical pathologist.

CHAPTER IX

The Research Institute

In our description so far we have constantly referred to research laboratories and institutes without giving any details of what is meant. Research can be carried on anywhere: it is the man doing it who will make it good or bad, whatever his circumstances. It has, however, been recognised that the search for basic facts in any science is best done in a place designed and set aside for that purpose. In medicine this has been provided for through a number of laboratories given over to pure research, such as the Pasteur Institute in France, the Lister Institute in this country and the Rockfeller Institute in America. These are all laboratories in which the investigation of any fundamental problem in medical research can be undertaken.

University departments have often the status of research institutes and in medicine much of the best work has come from the university laboratories. The professor in charge of these is always of recognised standing in research, and in addition to the staff of university teachers, often

has under him a number of people who are engaged full-time in research. There are various bodies in this country which give grants in aid of research and appoint special workers to research studentships in particular subjects; but a very large proportion of the research is subsidised by the Medical Research Council. This body which comes under the Privy Council, draws its funds from the annual taxation and gives grants to individuals and to departments as salaries, and for apparatus and expenses.

In addition, however, it has its own research laboratories, the National Institute for Medical Research, at Hampstead, with its associated field laboratory at Mill Hill. At the National Institute for Medical Research are working many of the best brains in medical research. All branches of medical research are undertaken and much benefit is derived from having them all under one roof. Here there is no need for a worker in one field to remain in difficulties over a problem that is outside his province for he is able to find a colleague who has the experience necessary to help him. The bacteriologist who thinks some phenomenon he has observed has a chemical basis can at once consult the chemical experts and pass the problem to them.

It is somewhat paradoxical that the research institute is finding that its prominent position in the research world is involving it in a considerable

amount of routine work. Certain preparations used in the treatment of disease can only be standardised by elaborate chemical tests, by comparison with recognised standards or by repeated animal experiments. In the first instance this involves research of the highest degree of accuracy and it is felt that only a research institute can be trusted with such work. Many of the methods now recognised internationally were evolved at the National Institute at Hampstead. In the testing of vitamins and of certain hormones, i.e. the secretions of the internal glands that control the functions of the body, this institute now holds the universally accepted standards. Certain sera, prepared from animals' blood, for the treatment of bacterial disease are also controlled here and altogether the Medical Research Council has had to accept a considerable amount of routine testing of this nature.

While we call it routine we have to remember that it requires a technique beyond the means of an ordinary laboratory. The work needs to be in the hands of men highly skilled in their own speciality.

In the course of its ordinary work a research institute divorced from a hospital has no direct access to the necessary materials from the sick. The research institute is here largely dependent on the clinical pathologist who can select the material and make it available to the research

worker. In research into the cause of a disease the material must in the first place be derived from human beings. The clinical pathologist, on the other hand, gets in return the benefit of the more specialised knowledge of those with whom he is thus associated.

This is in keeping with the usual rules of medical research, for all workers make not only their results but their methods and materials fully available to all other workers. A recent example of this with an unusual sequel relates to an animal disease. In Scotland sheep suffer from a condition known as "Louping-ill" which workers in this country have shown to be due to a filtrable virus. At the Rockefeller Institute in New York workers in various diseases were very keen to compare the virus of louping-ill with others, and material was at once sent to them by the British workers. The unusual sequel was, that in the American Laboratory, this virus, hitherto thought to be of danger only to the sheep, caused a few cases of serious illness among the laboratory staff. As they recovered, which fortunately all did, it was found that their blood contained a large amount of antibodies to the virus, indicating the exact nature of the disease and of the body's power of resistance. This discovery led to a testing of the blood of other laboratory workers in this country who had suffered from an undefined illness, and the

discovery was made that their blood also reacted strongly with the virus. They had also been victims of the louping-ill of sheep.

Louping-ill, we have said, is caused by a filtrable virus. A virus is a disease agent apparenty living, and similar in certain aspects to bacteria but so small that it is outside the range of any microscope. This makes research in virus diseases more difficult than in ordinary bacterial infections. The ordinary microbe can be seen microscopically and when grown on the usual culture media produces a visible growth. But viruses cannot be seen in either way and their presence can only be proven by their effects on animals or man.

This is one reason why so many animals are being used for experiments in medical research. Viruses cause a wide range of disease and we are only at the beginning of knowledge as to how they work, and how they gain entrance to the body. The research worker in this field of scientific research must use animals for his experiments or else forgo all chance of adding to human knowledge of their diseases.

To the research worker there is no question as to whether vivisection experiments on animals should be done or not: they are an indispensable part of medical research methods. The research worker is never fond of inflicting pain on any living creature, and in this country even brilliant

results are criticised if obtained at the expense of pain inflicted on animals. It is not claimed that pain is never inflicted; but, apart from the very stringent requirements of the law, those carrying out experiments take all safeguards they can to prevent suffering. Animals during certain experiments receive treatment as careful as would be given to human beings suffering from a similar condition, treatment all designed to minimise pain.

If any justification of vivisection is needed it has surely been given by recent work in animal diseases. It must be remembered that animals and plants suffer from diseases similar to those of human beings and man is always interested in ameliorating the suffering due to these conditions whenever it occurs. It so happens that the cause of many of these diseases are viruses and in working to discover the cause and treatment of human disease man may be forging a link in the chain of knowledge that will rid animals of a corresponding disease. The converse holds also, for our increasing knowledge of animal virus infections is assisting in clearing up the problems of human disease.

Two recent research announcements illustrate this in most convincing fashion. Everyone knows that distemper is a particularly deadly disease in dogs, a disease that infects nearly every dog and defies ordinary methods of prevention. So dis-

tressing was the death-rate from this condition, that some years ago a committee of dog-lovers raised a fund from which research at the Medical Research Council Laboratories was financed. The problem was a particularly difficult one, for no other disease behaves exactly as distemper does and so special methods had to be devised. In the end, however, man conquered. The disease was shown to be due to a filtrable virus; but, more important, a method was discovered by which a form of vaccine against the disease could be made. Inoculation with this renders the dog immune to the disease and even in large communities of dogs such as, for example, hunting packs, the case incidence has been kept down to an almost negligible percentage.

In the case of distemper man has been able to rid one species of animal, the dog, of its most deadly infection by means of experiments on other animals, chiefly ferrets. A result like that is more than enough to satisfy the research worker but it actually opened up the way to new discoveries in one of man's worst diseases—influenza. It has often been suggested that influenza and distemper were of a similar nature. The worker chiefly active against distemper was able to co-operate with other colleagues on the M.R.C. staff and the problem of what caused influenza was tackled in a new way. The work is still in an early stage but it has already been announced

that it can be shown that influenza is due to a virus and that it can be transmitted to animals.

The Lister Institute has been mentioned and one of its staff has recently completed another investigation which links up human and animal diseases in a surprising fashion. A number of people in the island of Trinidad died from a mysterious illness affecting the nervous system. It was thought to be an unusual form of a certain disease, and certain diseased tissues from the cases were sent to the Lister Institute for the opinion of their expert in that condition. Experiments showed that not only was it not the expected disease, but that the tissues actually contained the virus of rabies. This disease was thought to be completely absent from Trinidad where dogs are most strictly quarantined.

From this point a most interesting research began, the research worker in London co-operating with medical men in Trinidad. Rabies usually passes from an animal to man so the island was searched for a possible animal source. Some cows had died from an unrecognised malady so these were examined—although cows do not bite human beings! Strangely enough they were found to be infected with rabies in an atypical form. The research was not yet complete for it was obvious that an intermediate host must carry the virus from cattle to man. All the people who died were people who had slept in

the open, unclothed and it was then realised that the only possible carrier in Trinidad was the vampire bat which bites cattle and human beings indifferently.

One question which is receiving a very high proportion of all the medical research being done to-day is that of the cause of cancer. In hospitals everywhere surgeons are trying the powers of radium and X-rays against the different types of cancers that cause so much suffering and so many deaths. The degree of success varies and we are not yet within sight of any finality in the question of treatment. As with all diseases it is felt that if we only knew the cause of cancer we would be nearer a solution of the whole problem of cure. It has has been argued, and certain evidence has been produced that cancer is due to a virus, but that remains unconfirmed.

What the workers in this subject have managed to do is to discover a method by which, in animals, cancers can be produced with a considerable regularity. Tar and certain derivatives have been found to have this property and the chemists are now trying to track down the actual substance in those that possess this carcinogenic power.

We cannot conclude this chapter without mentioning that there is a very considerable amount of scientific work done by large commercial firms engaged in producing medical

supplies. This is especially so in the case of bacterial products and many of the anti-bacterial substances now available have been developed and improved by commercial firms. Their bacteriologists work in very close co-operation with other workers and are always very willing to pass on materials for corroboration of their claims. They also depend on clinical pathologists to supply them with materials and one example will show how important this may be.

Everyone knows that cerebro-spinal meningitis, caused by the meningococcus, is treated by injecting an anti-serum. It has been shown that there are two main types of meningococcus and the type chiefly responsible for any epidemic changes from year to year and place to place. It is therefore of the utmost importance to the commercial firms producing the anti-sera to obtain from the clinical pathologist strains of the germ from actual cases so that the anti-sera on the market at any time may be of the most potent type. Recent increased co-operation in this matter appears to have yielded much improved results.

These examples give an idea of the problems being investigated in the research institutes. Man has made many advances in medical science but he is still faced with enormous problems and difficulties. The infections still kill and incapacitate thousands every year and much remains to be done in the way of prevention.

In all this the research worker and the clinical pathologist have to co-operate at every stage, and all the available methods of research must be employed while more workers will be needed.

CHAPTER X

Research Outside the Laboratory

We have so far confined ourselves to research within the walls of the laboratory, and it is to give an impression of this that we are chiefly concerned. As there is, however, a very large volume of scientific research done outside the walls of a laboratory we must mention it briefly. There is no science which does not utilise the laboratory at some stage of its investigations, but some do a very large part of their work "in the field".

There is for example geology, which, as a study of the formation and constitution of the earth, must carry its work into every corner of the globe. The geologist requires both his microscope and his test-tube to complete his detailed knowledge of rocks, chalk, clay and the other strata of the earth, but the primary collection of data has to be done in the actual regions being investigated. The academic geologist is concerned with the great problems of how the earth assumed its present form, but there is the subsidiary problem of mapping out those areas

and strata of value to industry. This not only needs the help of the chemist to give accurate figures for the chemical composition of ores, but the practical mining engineer must give his opinion as to the accessibility of the strata.

Geology has also a connection with other sciences, for the geologist has to borrow some information as to the probable age of the earth from other fields which in their turn borrow from geology. The zoologist working out the details of evolution finds the geologist a great help not only in discovering specimens but in fixing a probable date for the period of the existence of their specimens as living creatures. The archæologist is another worker who wants what help the geologist can give, although as he is concerned mainly with the comparatively recent story of the earth he does not borrow much from this science.

Archæology draws much of its knowledge from the detailed records of work done by excavators on the sites of former towns and villages. The modern expedition in any geographical region does not dig in order to find works of art or precious objects, These have their place, but "the importance of archæological material is that it throws light on the history of men, on a civilisation which is bound up with that of to-day." The relation of objects found in the site under investigation may be of historical signifi-

cance; or the chance discovery of a small piece of pottery identical with that from a more exactly dated region may be a clue to the whole chronology of a site.

The archæological worker's use of the laboratory is chiefly for the purpose of preserving the objects he has discovered. Colours have to be restored, broken fragments pieced together, fabrics strengthened and a great variety of objects restored to something like their former state. When bones have been found they require careful examination, in which the anatomists assist, to determine the age and sex of the buried person. The reader must have noticed a few months ago how bones taken from an urn in Westminster Abbey were subject to an examination by means of which it was possible to determine the ages of the two princes who were murdered in the Tower of London.

Some archæological discoveries are of interest to those who specially study ethnology, which, although regarded by some as a minor branch of zoology makes use of a great variety of scientific methods. In trying "to treat of the various groups of human beings distributed over the face of the earth and describe their mental, moral and physical characteristics" the ethnologist studies not only their present state but their probable development from earlier communities.

The relation of one tribe with another may be

affected by many factors, geological, meteorological, physiological and zoological so that the ethnologist needs to borrow from all of these fields of research. The zoologist likewise finds aid in the sciences that study the development of the earth and its inhabitants and he calls in—and offers aid to—the various medical sciences.

Zoology also embraces entomology which has progressed far beyond the stage of being only what one might call a "cataloguing" science. The student of insects was for a long time concerned only with separating species and extending his knowledge of the insect structure, but in recent years his interest has spread beyond this. To begin with there was the startling discovery of the part played by insects in conveying disease from animal to animal, culminating in the demonstration that the mosquito carried the malaria parasite. Research then became necessary, and is still being pursued, as to the best methods of destroying these insects. Great successes have been achieved, and the death-rate from insect-borne infections in some parts of the world has dropped to a surprisingly low figure. There seems no reason why, by attacking the insect carrier, we should not rid the earth of a large number of virulent diseases.

Another branch of the biological sciences has found insects of great assistance in its studies, the science of genetics. The difficulty of proving any

theory in genetics is that most animal species breed so slowly that it would take more than a lifetime to observe the result of any particular experiment. With insects, (a fly called Drosophila has been chiefly used) a large number of generations can be observed in a very short period and large numbers of observations quickly made. It is a big jump from an insect to human beings and the domestic animals, but results obtained in the insect world have been shown to have remarkable similarity to what happens in the higher animals.

Insects enter into and interfere with many of man's activities: The swarm of locusts that sweep over and destroy the vegetation of Palestine, Arabia and Africa present science with a gigantic problem. Nearer home the humbler clothes moth can prove destructive both in the factory and the home. The ideal poison is one that can be incorporated in the material to be protected, but that is no easy matter, for colours are easily injured by other chemicals. Recently at Leeds, those doing research for the wool industry by a study of moths in a new way and by trying out new chemical compounds, appear to have found a method that gets rid of the trouble.

Insects play a very important part in agriculture, taking part in such an essential process as fertilisation on the one hand, and on the other, destroying fruits and plants. The latter question

is one of great difficulty for it cannot be solved in the most obvious way—by using substances poisonous to the insects—because of the danger of these poisons to man, animals and the beneficial insects. A variety of solutions have been put forward, the most interesting—and in certain instances the most successful—being that of introducing in large numbers another insect which destroys the one causing the harm. A simple example is that of the ladybird which feeds with amazing voracity on the green fly that infects our rose bushes.

The fruit grower wages a constant battle against these insect enemies and as he seeks help against them he also asks aid in other difficulties. We are all accustomed to having at our disposal an amazing variety of fruit, Californian peaches, and pears, Australian apples, Brazilian oranges, Jamaica bananas, South African plums and so on in infinite number. This is all a comparatively modern development and has meant much patient inquiry into the proper picking and packing of fruit. The farmer has had to find out at what stage of ripeness he should pick his crop so that it will travel across the world and arrive at the retail market in perfect eating condition.

Science has had to be called in to devise methods of storing these fruits both on the journey and in this country. A large research station in Kent possesses a special type of building in which

all climatic conditions can be reproduced and the fruit tested under storage conditions such as it would meet on a journey, say, from Australia to London. Apples can be "put to sleep" so that at the end of a year they come out of storage in a condition which in natural surroundings would be reached in a few weeks.

There remain for mention two types of laboratory of exceptional interest. The type of research they do has to be confined to a small space, and yet their field of activity takes them out into regions few men have visited. One of man's interests has always been the sea, and especially what goes on in the depths of the ocean. Trawling and sounding are the traditional methods of obtaining information about the bottom of the sea, its structure and its inhabitants. Deep-sea diving has now reached a stage where man not only goes down to a greater depth but stays down for longer periods. This also is the result of scientific experiment but it still does not provide the ideal method of observing the sea-bottom. An American scientist some years ago devised a method of overcoming this by building an observation sphere capable of withstanding the pressure of water at a considerable depth, reached by a vertical shaft and supplied with windows and lights. In this strange laboratory many observations of scientific importance have been made on the habits of deep-sea fishes.

In the other direction man has been ascending far above the surface of the earth into regions where no life, as we know it, can exist. The balloon ascents that have been made into the stratosphere serve a very large number of scientific purposes. They give a new indication of what the balloonist can do; they show what strength with lightness the modern metallic alloys can provide, for the sphere in which the balloonists ascend is made of one or other of these metals. They also show that man can enclose himself in a space and provide in it his own atmosphere even in places where the oxygen content of the air is below the level needed for life. But the real purpose of these flights is to carry into the stratosphere a complete laboratory. The sphere of the balloon is full of the most delicate instruments for making records of the conditions through which the balloon passes. The maximum height reached is recorded automatically. The function of this "flying" laboratory is to make observations of phenomena that cannot be accurately made in the ordinary earth-bound building.

Everyone is now familiar with the conception of "rays" produced by electrical apparatus, by radio-active elements or occurring naturally. Man makes use of the ultra-violet rays occurring in sunlight and in artificial lighting of certain types. We are familiar with X-rays, themselves

invisible but capable of penetrating solid structures and of giving us pictures on photographic plates. We have already mentioned the infra-red rays and the attempt to use them for photography over long distances. To the physicist there are many other rays all yielding information as to the structure of matter. Among these are the "cosmic" rays arising somewhere beyond the range of the earth and its atmosphere, but possessed of great force and remarkable penetrative power. It is in order to study these rays under conditions free from interference that man now takes his spherical laboratory, attaches it to a balloon and ascends into the stratosphere.

Enough has been said to show that the laboratory worker has visions that carry him far beyond the walls of the rooms in which he works. Sometimes his researches take him back to the times when man lived a far simpler life, sometimes forward to the future of control over forces yet unguessed, and very often on a trail which leads to some problem of practical importance to his fellow-men in industry.

CHAPTER XI

Industrial Research

The heading of this chapter might be the title of a whole encyclopædia, for industrial research has developed to such an extent that it merits a description running into many volumes. Here one can only indicate in the briefest way something of what is being done in a few industries.

Industrial research in this country has been to a certain extent the subject of very haphazard development and an investigator would find that the extent to which the laboratory is used in different industries varies very widely. Since 1918 there has been an element of co-ordination through the work of the Department of Scientific and Industrial Research. That department has set up laboratories of its own, taken over or assisted others in which fundamental research is being carried out and it co-operates with any manufacturer who has a practical problem that can only be solved by laboratory methods.

Its chief laboratory, which was not originally financed by the state, is the National Physical Laboratory at Teddington. We have already

spoken of the National Institute for Medical Research and the work it does not only in absolute research but also in the setting up of standards for biological products. In other sciences and in industrial research the National Physical Laboratory is the centre for the standardisation of methods and measurements.

The National Physical Laboratory covers a very large surface area, and is really a collection of laboratories, each dealing with a different subject. Throughout, one is probably correct in saying, the chief pride of the workers is the remarkable degree of precision reached in its measurements. Apparatus, balances, measures, electrical resistance and so on certified by the Teddington laboratory as accurate are accepted everywhere as answering the highest standard of accuracy. Within its laboratories measurements of the smallest quantities of radium and the checkings of the lengths of wireless waves go on in buildings not far from the laboratory where insulators are tested by currents up to one million volts.

The industrial problems dealt with by the National Physical Laboratory are as varied as industry itself. At one end of the scale are its sensitive tests of clinical thermometers, all of which are accurately checked before being sold to the public. At the other end are its experiments on aeroplanes and ships. By means of its wind-

tunnels in which scale models can be placed, the exact performance of an aeroplane can be measured. In the great water tanks, scale models —in wax—of ships are towed up and down so that their resistance to water under varying conditions can be measured. Any ship builder can ask for a test to be made on ships he proposes to build and much valuable information is thus obtained.

In other departments new alloys are being made and tested so that their value for industrial purposes can be estimated. Metals and metallic products can be observed under stresses and strains such as they might meet in industrial conditions. Thus the couplings used for linking up the carriages of trains are tested for the maximum load they will pull without fracturing. Gauges, so necessary for the accurate measurement of many engineering components, are tested in large numbers, the testing machines themselves being marvels of ingenuity and accuracy.

One important piece of work done at Teddington is the comparison of standards of measurement as kept in various countries. Common measures such as the yard and the metre, are kept at the National Physical Laboratory under conditions as to temperature that can be controlled and are measured to a degree that is almost inconceivable to those not accustomed to

scientific methods. But science is international and it is necessary that the standards of measurement should be exactly the same in all countries and the British laboratory, therefore, works in collaboration with similar institutions abroad so that the accepted standards may be exactly the same everywhere. There is an International Bureau of Weights and Measures and the Teddington laboratory has made very considerable contributions to its work. One question has particularly engaged its attention, that of accurately measuring temperatures, and methods are now available for covering a range of almost four thousand degrees centigrade.

Within the grounds at Teddington is another laboratory of the Department of Scientific and Industrial Research, that given over to chemical research. This laboratory is dealing with a number of chemical questions arising in industrial processes. Methods may be discovered here that will affect the whole progress of an industry. Probably the coal industry is that in which the greatest interest is being taken, for everyone recognises that we are only beginning to make use of coal as we should.

To the lay public coal is something to be burned in an ordinary fire. To the chemist coal is the most marvellous storehouse of valuable chemicals. Not only does it provide heat, and from that energy, but the industrial chemist

extracts from it inert substances such as the resins used in making bakelite, highly inflammable oils and spirits, perfumes, dyes of every colour, and drugs and antiseptics for human use.

The chemical industry is the greatest commercial user of research methods for the reason that all its methods are built up on the work of the laboratory. The methods of the test-tube, retort and boiling-flask require to be translated into a different technique to produce chemicals on a commercial basis, but the whole process remains a chemical one.

In other industries the basis of manufacture is not chemical and the chemist has therefore a very different function. There may be certain problems that require chemical research but the chief function of the chemist is to control the industrial process, its raw materials and its finished products. In addition, the chemist is often the man who has to sort out errors and complaints. He must be not only a widely experienced chemist but must know every stage of the manufacturing processes he controls.

Retail business men are to-day employing the chemist to some extent in this question of control. The small retailer obviously buys his goods from warehouse and factory on the guarantee of the firm making these goods. But we have many large chains of stores, both private and co-operative which purchase goods in such large

quantities that it sometimes pays them to employ a chemist to control the standard of certain commodities. When, in addition, they make much use of coal, oil, petrol, etc., they may find it economically worth while to have these things checked by their own experts.

We have made very little mention of the wireless industry, not because it is not based on scientific work but because it is to such an extent the direct outcome of fundamental research that it is too big a subject to discuss here. The advance made in the broadcasting and reception of speech and music has only been possible because those concerned in these subjects from the commercial aspect have employed a large number of scientific workers on the subject. While the manufacturer has had to develop new machinery for the making of delicate apparatus such as wireless valves, the advances in the technical performance of them have all come from the work in the laboratory. We shall probably see even more wonderful advances, for in addition to our ability to transmit sound we are now able, through television, to send images of persons and things over long distances.

In something of the same field we have been witnessing advances, due to research, in the ordinary telephonic method of communicating over distances. The telephone is now so much a part of civilisation that those who use it seldom

stop to consider how marvellous it all is. To the telephone expert it presents almost innumerable opportunities for research, and in this country the Post Office has established its own research station. The transmission of sound over long distances requires very special qualities in the conveying wires if the quality of the sound, the clarity, for example, of the words, is not to be lost. The fact that very large numbers of messages have to go through certain types of apparatus without interruption means that that apparatus must be as nearly fool-proof as possible.

The extension of the automatic system of telephonic communication is in many ways the greatest wonder of the whole system. It is almost uncanny to see at work the machines that make the connections, selecting lines, recording the calls, clearing the lines at the finish of a call and so on without human intervention. More uncanny still is the fact that the engineers have an equally mechanical method of testing all this vast mechanism with its thousand upon thousand wires. There are still some functions which can only be done by the human being but they are rapidly becoming fewer and fewer.

All the heavy metal industries use the services of the chemist, especially as it is now seen that very small quantities of certain elements make great differences to the final product. Without the chemist we would not have seen the new

rustless steels and processes like chromium plating. These require careful control for not only is the exact amount of the ingredients of importance, but small quantities of unusual chemicals may ruin the whole output.

Steel is now a very important building material but its use for that purpose raises a number of quite unexpected problems. Building materials were formerly judged by the experience of the builder, but that is not sufficiently accurate for the present day. Building research has now developed as a branch of the Department of Scientific and Industrial Research and it is possible to test concrete, bricks, wood, steel and tiles for strength, durability and sound conduction. That sound should not be conducted is very important in modern buildings and the National Physical Laboratory has a new building in which materials of any description can be tested for their ability to pass or stop sound waves.

New knowledge is needed and is being urgently sought both at Teddington and elsewhere on the subject of noise. It is obvious that much of the noise of a modern city could be prevented by scientific means, and it is felt by many that man must suffer from the continual noise of modern life. At the same time a complete silence is unbearable to most people and it follows that the perfect house must be constructed so as to allow

only that amount of noise which the average person finds suits him best.

In this connection the curtains and furnishings of a house are an important item because most textiles absorb sound waves. Textiles are no longer the comparatively simple products of cotton, linen or wool of a former age, and the textile industry needs its scientists not only to develop its new materials but to see what effect they have in other industrial processes. The textile industry is probably one of the best examples of how much research can give to an industry. Not only have the traditional fabrics been altered by a variety of chemical treatments, by new methods of dyeing and finishing, but new machinery for speedier manufacture and more standardised products have all been invented in recent years. Most important of all is the number of new fab[illegible] that have appeared. Some, it is true, have been partly accidental but the greatest number and most important have been the outcome of research.

The whole "Celanese" industry has a purely chemical basis. Cellulose, like the chemicals derived from coal-tar, has such a myriad uses that few people not expert in industrial chemistry can follow their development. Cellulose is a constituent of all vegetable matter so that man has many sources of supply, but he now uses such quantities that other research is initiated to

increase certain vegetable products. Whatever its source the chemist begins by dissolving and purifying the raw material. It can then be used as a basis for paints, for paper wrappings, unbreakable glass, or, most marvellous of all, a variety of textiles beyond the dreams of even the pre-war generations.

The older fabrics still have their place, of course, and the chemist has been called in to make them more attractive, more durable, more easily handled and so on. He proceeds to a complete examination of the structure of wool, cotton and linen and then proceeds by a variety of processes to make one look like another or like something different from either. None of this is easy, and it is said that the scientists attached to one firm spent fourteen years in carefully worked-out research which resulted in the recently marketed uncrushable cotton. Much time has also been spent on the problem of making a woollen fabric that would not shrink. In the process of manufacture the wool fibres are pulled and strained and it is as a result of this that shrinkage afterwards occurs. Now a machine has been devised which takes the woollen cloths and presses the fibres back to their natural length so that shrinking is impossible.

Some of these researches have led very far afield, for from the study of wool the search goes back to the sheep, and the whole question of what

influences the quality of wool. This has started research at such places as the Animal Breeding Station at Edinburgh and the Rowett Institute at Aberdeen. Sheep-breeders know that certain types of sheep always grow a particular class of wool, but the scientist wants to know what effect local conditions, the type of grass and the chemicals in the soil have on the wool.

This is one of a type of problems arising everywhere in agriculture. We regard farming as one of the most conservative of industries, based on century-old traditional methods. This is no longer true of agriculture as a whole though it may still hold for quite a number of individual farms. Agriculture in this country is now as well provided with research stations as any other industry, some privately owned, others at universities or controlled by the state.

The botanist is still producing new types of wheat seed and uses methods based on observations of the characters of wheat grown on different soils. Other plants, especially grass, are being produced in new and more prolific types and the work done at the Welsh Plant Breeding Station at Aberystwyth suggests that we may some day see the apparently useless sides of our hills and mountains covered with grasses capable of feeding many more sheep than at present.

The whole problem of animal nutrition is being investigated vigorously, for with the recognition

of the importance of diet in man it has become obvious that animals may suffer as man suffers if the diet is not adequate. In the case of dairy cattle it has to be remembered that we expect a cow to produce milk far in excess of her normal yield, and for a longer time, so that her diet must be large enough and varied enough to sustain her in health during that demand. To make observations of value in research of this type requires very elaborate tests spread over a very long period and can only be done in an institution run on a national basis. Results obtained in the research institute must be shown to yield practical results to the farmer and this is largely done through the stations of the National Institute of Agricultural Botany.

The farmer supplies a national rather than a local market, for his products usually go, by contract, to large concerns dealing with the public. Thus the greater part of the milk of London is handled by a number of very large firms who draw their supplies from all over Great Britain. Milk, one of the most valuable of foodstuffs, is also one of the most liable to bacterial contamination and spoilage. Those firms who bring milk over a long distance are faced with the problem of preserving the good qualities of the milk.

This has meant the building-up of a chain of laboratory control, beginning at the primary

collecting station and making tests at every stage until the milk reaches the consumer, some thirty-six hours later. This laboratory control is both chemical and bacteriological and has proved of immeasurable value to both the dairy and the consumer by enabling the quality of the milk to be kept constant. Those dairies which have their own control laboratories have their self-imposed standards of cleanliness and purity.

The scientific control extends, of course, to the other dairy products, butter and cheese. In the production of these there is, as a by-product, a large amount of whey which has often been treated as waste. The chemist, naturally, does not regard that as a thing to be encouraged and research is going forward on new ways of utilising even the whey. Milk is a mixture of various substances one of the chief being the protein, casein. This has provided one of the romances of modern industry for the chemist has shown how this animal product can be solidified, coloured, polished and worked up into a variety of products, useful and ornamental, with a ready sale.

Of our traditional industries fishing is of equal antiquity with farming and does not, on first consideration, suggest much scope for the scientist. In recent years, however, the fishing industry has begun to see that it can get as much benefit from scientific methods as any other industry. The improvement of methods of fishing is one for the

practical fisherman, but there are other factors which need intensive research methods. There is the question of the preservation of fish after it is caught. Fish is now taken from the water at places very distant from the nearest port and has to be kept in good condition until it arrives at the markets. This has meant prolonged investigations into freezing and other methods of preservation, and the ideal method has not yet been found although progress has been made.

The most helpful research has been on the habits and breeding places of fish. One thing that has always disturbed the fisherman is the fact that a type of fish may be plentiful in one district for years and then suddenly disappear. Research has shown that the cause of this lies in the amount of feeding matter present in the water which depends, for example, on the temperature of the water. The effect may be spread over a number of years and the problem now to be considered, by taking observations over a period of years, is to what extent the movements of fish can be forecast. There is also the question of growth of fish and of movement among adult fish. By marking fish with dated discs at one place and mapping out the places at which they are caught again some surprising results have been obtained. The scientific study of the principal food fishes has now been internationalised, certain fishes being allotted to particular nations and the results of

these sectional studies are made available for all by means of international conventions and publications.

It would take too long to tell all that is being done in other industries. We might discuss the problem that faces the manufacturer of boots and shoes who is looking to science for a method of preparing leather which will allow air to circulate through the finished article without altering its waterproof qualities. No mention has been made of the attempts of those trades dealing with confectionery to standardise such products as jams or to ensure that lemon-cheese will have some connection with the fruit that gives it its name. Paint manufacturers are not content to put a new type of paint on the market unless it has stood the test of all kinds of weather conditions and very elaborate methods for reproducing these are devised in the laboratory.

All these and many other industries are basing their production on the result of research and it should now be clear, we think, that research is possible in every industry, and that despite what has been done there is still ample scope for more work and workers. We will consider this more fully in the final chapter.

CHAPTER XII

The Future of Research

The archæologist and geologist tell us that man's life as a civilised being has been very short, and we know that the historical period has been only a very few thousand years. It is only during the last few hundreds of them, and particularly the last century, that research has played any real part in man's activities. It is therefore quite clear that we are really only at the beginning of our investigations, not only into the absolute facts of nature, but also as to how they can be used by man. The problems so far solved are small compared with those still remaining.

Man has still much to discover about himself, and particularly about his own mental processes and their development. Psychology is one of the youngest of sciences, and the number of people in this country who can be considered experts in it is remarkably small. There can be no question that by the use of methods based on what is already known of man's psychological processes great changes can be made in the outlook of the mass of the people. The student of social psycholo-

gy wants to find out more about this and wants to learn in what way man's behaviour can be made to fit in with the needs of the state.

Research in this field will require to be greatly extended, and more trained experts are needed. So also is there a need for those trained in the very modern science of Industrial Psychology which is capable of exerting very powerful influence in increasing the efficiency and lessening the fatigue of modern industry. There is an Industrial Research Board, controlled by the Medical Research Council, which institutes inquiries into these problems but the greater part of the work in this country is done by the National Institute of Psychology, a privately managed concern. This body has carried out many inquiries and has given much advice on particular problems, but it only touches the fringe of the subject. In a recent broadcast talk Professor Julian Huxley pleaded that the ideal would be for this subject to be encouraged and financed by the Government, and that tests, on the lines already shown to be beneficial, should be compulsory throughout industry.

The question of how far the State should make itself responsible for research is one that will probably be much debated in the near future. It is always suggested that men placed in secure positions tend to show less initiative than those in competitive employment. This does not, however,

appear to have any great weight in research laboratories for the true research worker is concerned with his problem as a problem that must be solved, and not as a means of retaining his position. In the laboratories already financed by the State, those of the Medical Research Council, and those of the Department of Scientific and Industrial Research the work that has been done has been of the very highest value and has, in many cases, been carried out with a speed and zeal that could not be excelled.

In those laboratories of commercial firms in which pure research is done there does not appear to be any attempt to link up the security of the research worker with the obtaining of results. There are very large research centres, in photographic firms and in the oil industry, where the scientists are able to tackle any problem connected with their subject without interference from those in control of the commercial side. Research personnel requires to be carefully chosen and trained, and if that is done the results will be obtained either in the laboratories of the commercial world or of those owned by the State.

It is to be remembered that certain State laboratories in this country are recognised internationally as of the highest standing in the world. The cost of these to the nation is comparatively small for the Medical Research Council receives less than £150,000 while the Department of

Scientific and Industrial Research finances all its laboratories out of a little over £500,000. The State spends rather more than that in research for their departments concerned with destruction rather than production—the Army, Navy, and Air Force.

It is difficult to discover how much money is spent by industrial concerns, but it may be in the region of two million pounds, which, however, cannot be regarded as excessive in proportion to the turnover of industry. A few concerns run very large research departments, and quite a number have very efficient control laboratories, some employ consulting scientists and many subscribe to research associations. Nevertheless it has been estimated that there are probably over 100,000 factories in which there is neither scientific research nor control. For the smaller factories—and there are many thousands employing less than one hundred workpeople—research is as essential as for the larger concerns, but it can only be carried out by centralised laboratories acting for a number of factories in association.

Many of the smaller factories do gain some benefit from research for they may employ machinery made by larger firms after much work has raised the efficiency of the machine. There is also the fact that many firms manufacture articles "under licence" from other firms who have originally done the research

that led to the development of the patented article.

This is bound up with the whole question of patents. We have already pointed out that firms running research laboratories do not refuse to publish newly-discovered improvements, but that they endeavour to cover all probably useful developments by patent. Under a national State subsidiary system of research, this would not be possible in its present form, or the desired improvement in industry would not take place. The State would require to protect itself in some way, but the results would need to be freely available to those industries making use of the centralised research. The simplest method is, of course, that of the medical profession in which all research results are available to every research worker in every country in the world.

Research certainly does not recognise the ordinary national boundaries, and the amount of scientific literature in circulation in every country in the world is becoming alarming. The larger commercial research departments in this country have all recognised this problem and one finds that they usually have a library, and often a librarian, so that the latest work should be easily accessible. In medical literature there are a number of journals which publish nothing but a summary of current literature. The result is that very little that is new in any particular field

escapes the notice of those interested in that subject, leading to more rapid advances as ideas are thus pooled.

It is extraordinary the way in which ideas spread throughout the sciences. A notable example at the moment is the phenomenon of fluorescence. Ultra-violet rays, which we have previously mentioned are themselves invisible, but when allowed to strike certain substances in a dark room they cause those substances to glow with a light and colour not their own. This fluorescence is finding an amazing variety of uses. It has been used to detect the spores of the organism causing ringworm in the hair. It can be used to separate quite closely related germs. In the case of certain vegetable oils it has been found that while a pure oil does not fluoresce an adulterated one probably will. The same applies in certain kinds of motor spirit. In the manufacture of rubber it also has its uses, for certain chemicals not otherwise distinguishable fluoresce with a different colour. Those interested in the action of ultra-violet rays have here a field for further experiment.

Most scientific subjects appear to be constantly extending their field, and there are still many romantic discoveries to be made. Chemistry has just had a whole new vista of discoveries opened up by the demonstration that pure water, as we have already mentioned, is not a single chemical substance as was believed, but a mixture of two

different types of molecules. Such a discovery in the case of one chemical substance means that all others have to be examined for similar possibilities and when new substances are thus disclosed they have in their turn to be analysed.

The structure of the atom is slowly yielding to new methods of investigation, and the physicist is now able not only to break up atoms but to observe what happens to electrons, protons and neutrons, conceptions that to the lay person seem completely beyond human comprehension. Whether we shall tap the great sources of energy that lie concealed in the atoms of various elements is still doubtful, but we appear to be getting nearer to a conception of matter that may be the limit of what research can discover in that direction.

We have already discussed some of the medical problems awaiting solution, especially that of the cause and cure of cancer. Slowly man is tracking down the cause of all his innumerable infectious diseases and the next step will be to indicate how these evil things can be banished from the earth.

Another field in which man is just on the threshold of new discoveries is in the biological sciences. Genetics is a complicated subject but in the breeding of animals wonderful results have been obtained. In such animals as foxes and rabbits used for making furs for women, the breeding expert has shown how to breed pure strains giving coats with particular characteristics. Cer-

tain types of fox fur that were formerly a rarity in Nature can now be imitated very closely by following a special method of cross-breeding rabbits.

In the case of animals the genetic expert is endeavouring to standardise certain qualities needed for commercial purposes. In the case of human beings it is not standardisation that is wanted but a general improvement along with variety. This may be possible but it requires two points to be clarified first. It is not agreed what qualities are desirable in mankind and we have not yet all the data necessary to enable rules for the attainment of that improvement to be laid down. At the moment there is no national research on any point in human genetics being done.

One may be bold enough to say that whatever other developments the future holds, one that must come is a recognition of the help that research methods can give the State in improving the quality of its citizens. There is an enormous amount of data still to be collected in regard to the nutrition of all classes of the community. There is much to be done on the factors that make for resistance or susceptibility to disease. There are many hereditary factors on which information is scanty or non-existent and we have no generally adopted method of vocational guidance.

THE FUTURE OF RESEARCH

Research in industry is going to continue its process of improving methods of production and providing man with new and better products so that more and more leisure will be available for every member of the community. Parallel with this surely it must be the duty of the State to carry out those biological and psychological studies of the people that will enable them to make full use, both for themselves and posterity, of the leisure and plenty with which scientific research applied to industry can supply the world.